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Properties Of Fluids

Properties of Fluids

① Mass Density $\rho = \frac{mass}{volume}$

② Weight Density $= \frac{weight}{volume} \; (= \rho g)$

③ Specific Volume $= \frac{1}{\rho}$

④ Specific gravity $= \frac{\text{wt. density of liquids}}{\text{wt. density of water}}$

⑤ Viscosity (Dynamic viscosity)

$$\tau = \mu \frac{du}{dy} \Rightarrow \boxed{\mu = \frac{\tau}{\left(\frac{du}{dy}\right)}}$$

$\boxed{\text{CGS - poise}}$

$\boxed{\text{SI} - \frac{Ns}{m^2}}$

⑥ Kinematic Viscosity $\boxed{\nu = \frac{\mu}{\rho}}$

$\boxed{\frac{cm^2}{s} \rightarrow \text{stoke}}$

Variation of viscosity with temp

liquids $\mu = \mu_0 \left[\frac{1}{1+\alpha t+\beta t^2} \right]$

gases $\mu = \mu_0 + \alpha t - \beta t^2$

Classification of Fluids

- Newtonian $\tau = \mu\left(\frac{du}{dy}\right)$
- Non-newtonian
  - Purely viscous
    - Time independent
      - Pseudoplastics $\tau = \mu\left(\frac{du}{dy}\right)^n, n<1$
      - Dilatant $\tau = \mu\left(\frac{du}{dy}\right)^n, n>1$
      - Ideal plastics/Bingham fluids $\tau = \tau_0 + \mu\left(\frac{du}{dy}\right)$ $n=1$
    - Time Dependent
      - Thixotropic
      - Rheopectic

      $\tau = \mu\left(\frac{du}{dy}\right)^n + f(t)$
  - Visco-elastic fluids $\tau = \mu \frac{du}{dy} + \alpha E$

Compressibility

$$K = \frac{dp}{\left(\frac{-dV}{V}\right)}$$

Surface Tension

$p = \frac{4\sigma}{d}$ liquid droplet

σ → surface tension
d → dia. of droplet
p → pressure inside droplet

$p = \frac{8\sigma}{d}$ bubble

$p = \frac{2\sigma}{d}$ liquid jet

Capillarity

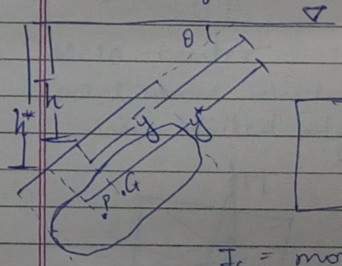
$h = \frac{4\sigma\cos\theta}{wd}$

θ → angle made with meniscus
d → dia of capillary
w → sp. wt. of liquid

Hydrostatic Forces On Surfaces

Center of Pressure — point at which entire pressure of fluid acting can be assumed to be concentrated.

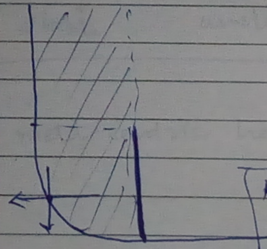
Force ~~of~~ on Inclined Plane



$$\boxed{h^* = \bar{h} + \frac{I_G \sin^2\theta}{A\bar{h}}}$$

I_G = moment of inertia of plane about ~~surface~~ COG (G).

Curved Surface In liquid



The curved surface can be assumed to be made up of 2 parts. Horizontal & vertical

~~Horizontal~~ Vertical force = wt. of shaded water column.

~~Vertical~~ Horizontal force = force on bolded face (using above formula)

$$\boxed{F = \rho A g \bar{h}}$$

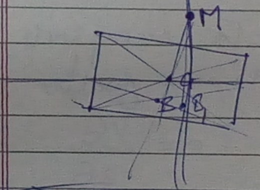
Buoyancy

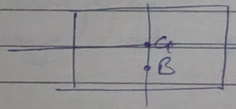
$$\boxed{\text{wt. in air} - \text{wt. in water} = \text{wt. of water displaced}}$$

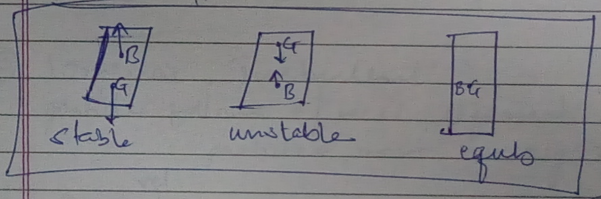
Stability

Meta-center

point about which body starts oscillating when tilted slightly over a liquid.






B
G
stable
G
B
unstable
BG
equlb

$$\text{meta-centric height} = GM = \frac{\boxed{I}}{\boxed{\forall}} - BG$$

I → MOI of cross-section vertical to water surface

∀ → vol of body submerged in water

Oscillation of Rolling body

$$\boxed{T = 2\pi\sqrt{\frac{K^2}{\underset{\downarrow}{(GM)}\,g}}}$$

distance between G & metacenter or metacentric height.

Kinematics of Flow

Types of flow:—

① Steady & Unsteady

↓ fluid props like vel. /(pr)/ density don't change.

$\boxed{\frac{\partial v}{\partial t} = 0}$, $\boxed{\frac{\partial \rho}{\partial t} = 0}$ $\boxed{\frac{\partial p}{\partial t} = 0}$

② Uniform, Non-uniform

↓ velocity doesn't change wrt space.

$$\frac{\partial v}{\partial s} = 0$$

③ Laminar, Turbulent

↓ particle follows a well defined streamline

↓ particles move in zig-zag pattern

$$R_e = \frac{\overset{\text{vel}}{\uparrow}\;VD \rightarrow \text{dia}}{\nu \rightarrow \text{kinematic viscosity}}$$

$$\underbrace{2000 < R_e <}_{\text{intermediate}} 4000 \rightarrow \text{turbulent}$$

← laminar

④ Compressible & Incompressible –

$$\frac{\partial \rho}{\partial s} = 0$$

⑤ Rotational, Irrotational Flow

If $\left(\frac{du}{dy} = \frac{dv}{dx}\right), \left(\frac{dv}{dz} = \frac{dw}{dy}\right), \left(\frac{dw}{dx} = \frac{du}{dz}\right)$

then flow is irrotational.

⑥ 1-D, 2-D, 3-D flow

$$\boxed{\text{Rate of flow} \quad Q = A \times V}$$

$$\boxed{\text{Continuity Eqn} \quad \rho_1 A_1 V_1 = \rho_2 A_2 V_2}$$

$$\boxed{\text{Continuity Eqn} \quad \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0}$$

Allmate

Velocity and Acceleration

let u, v, w be components in 3 dirⁿs –

$$\boxed{V = \sqrt{u^2 + v^2 + w^2} = u\hat{i} + v\hat{j} + w\hat{k}}$$

accelerations –

$$a_x = \frac{du}{dt} = \frac{\partial u}{\partial x} \cdot \frac{dx}{dt} + \frac{\partial u}{\partial y}\frac{dy}{dt} + \frac{\partial u}{\partial z}\frac{dz}{dt} + \frac{\partial u}{\partial t}$$

$$a_y = \frac{dv}{dt} = \frac{\partial v}{\partial x}\frac{dx}{dt} + \frac{\partial v}{\partial y}\frac{dy}{dt} + \frac{\partial v}{\partial z}\frac{dz}{dt} + \frac{\partial v}{\partial t}$$

$$a_z = \frac{dw}{dt} = \frac{\partial w}{\partial x}\frac{dx}{dt} + \frac{\partial w}{\partial y}\frac{dy}{dt} + \frac{\partial w}{\partial z}\frac{dz}{dt} + \frac{\partial w}{\partial t}$$

convective accⁿ

local accⁿ

Velocity Potential Fn – (ϕ)

A fn such that

$$u = -\frac{\partial \phi}{\partial x}, \quad v = -\frac{\partial \phi}{\partial y}, \quad w = -\frac{\partial \phi}{\partial z}$$

Also

$$\boxed{\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{\partial^2 \phi}{\partial z^2} = 0}$$

Rotational components —

$$\omega_x = \frac{1}{2}\left[\frac{\partial w}{\partial y} - \frac{\partial v}{\partial z}\right]$$

$$\omega_z = \left[\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right]$$

$$\omega_y = \frac{1}{2}\left[\frac{\partial u}{\partial z} - \frac{\partial w}{\partial x}\right]$$

$$\boxed{z \leftarrow y \leftarrow x}$$

Stream Function

scalar fn of space & time such that its partial derivative wrt. any dirn gives the velocity component at right angles to it.

$$\boxed{\frac{\partial \psi}{\partial x} = v} \qquad \boxed{\frac{\partial \psi}{\partial y} = -u}$$

For irrotational flow, $\frac{\partial^2 \psi}{\partial x^2} + \frac{\partial^2 \psi}{\partial y^2} = 0$

Equipotential line

Along which potential is constant

$$\boxed{\frac{dy}{dx} = -\frac{u}{v}} = \text{slope of the equipotential line}$$

Line of constant stream fn —

$$\frac{dy}{dx} = \frac{v}{u}$$

Equipotential line & line of constant stream fn are perpendicular to each other.

Relation between stream fn & velocity potential

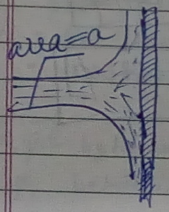
$$\boxed{\frac{\partial \phi}{\partial x} = \frac{\partial \psi}{\partial y}} \qquad \boxed{\frac{\partial \phi}{\partial y} = -\frac{\partial \psi}{\partial x}}$$

$$\boxed{u = -\frac{\partial \phi}{\partial x} = -\frac{\partial \psi}{\partial y}} \qquad \boxed{v = -\frac{\partial \phi}{\partial y} = \frac{\partial \psi}{\partial x}}$$

If $\vec{F}$ is irrotational, then ϕ exists such that $\vec{F} = \text{grad}\,\phi$. ϕ is scalar potential fn.

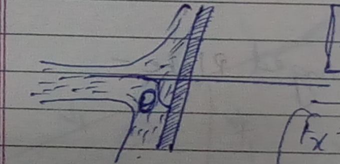
Jet Propulsion

①



$$\boxed{F_x = \rho a V^2}$$

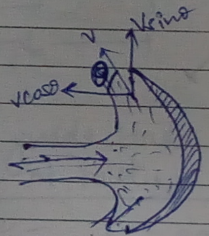
②



$$\boxed{F_n = \rho a V^2 \sin\theta}$$

$$\boxed{F_x = \rho a V^2 \sin^2\theta} \quad \boxed{F_y = \rho a V^2 \sin\theta\cos\theta}$$

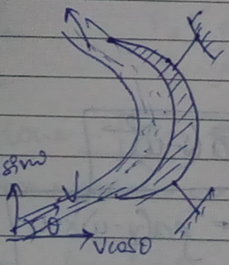
③


V sinθ
V
θ
V cosθ

$$\boxed{F_x = \rho a V^2(1+\cos\theta)}$$

$$\boxed{F_y = -\rho a V^2 \sin\theta}$$

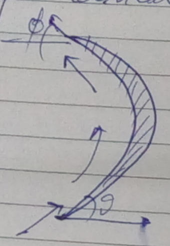
④


V sinθ
θ
V cosθ

$$\boxed{F_x = 2\rho a V^2 \cos\theta}$$

$$\boxed{F_y = 0}$$

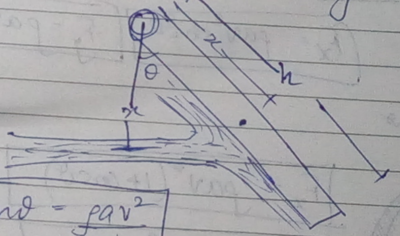
⑤ Unsymmetrical Plate



$$\boxed{F_x = \rho a v^2 [\cos\theta + \cos\phi]}$$

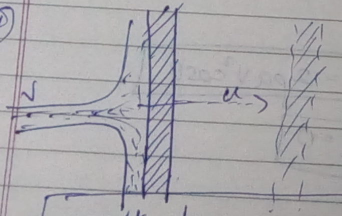
$$\boxed{F_y = \rho a v^2 [\sin\theta - \sin\phi]}$$

⑥ Force Exerted on Hinged Plate -



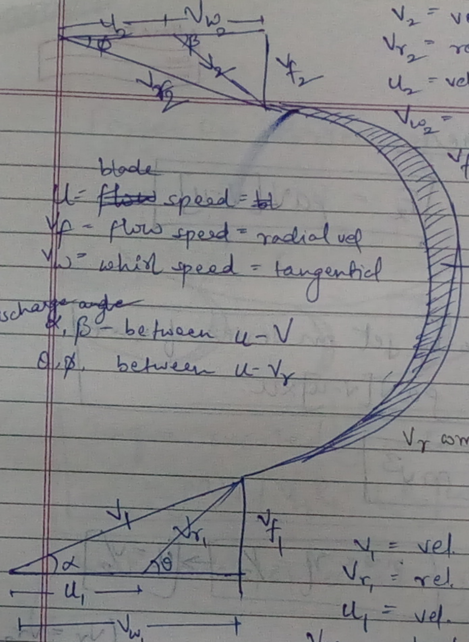
$$\boxed{\sin\theta = \frac{\rho a v^2}{W}}$$

⑦



$$\boxed{F = \rho a (v-u)^2}$$

$$\boxed{\text{work done per second} = \rho a (v-u)^2 \times u}$$



V_2 = vel. of jet leaving
V_{r_2} = rel. of jet ~~[illegible]~~
u_2 = vel. of vane ~~at outlet~~
V_{w_2} = whirl vel. at outlet
V_{f_2} = vel. of flow at outlet

ϕ = vane angle at outlet
β = guide blade angle at outlet, jet angle at outlet.

blade
u = ~~flow~~ speed = ~~[illegible]~~
V_f = flow speed = radial vel
V_w = whirl speed = tangential

discharge angle
α, β - between u - V
θ, ϕ, between u - V_r

u → v - V_r
V_w → v - V_f
V_r comes out as tangent

V_1 = vel. of jet at inlet
V_{r_1} = rel. vel. of jet and plate
u_1 = vel. of vane at inlet
V_{w_1} = whirl vel. of jet at inlet.
V_{f_1} = flow vel. at inlet.
α = guide blade angle at inlet, jet angle at inlet
θ = vane angle

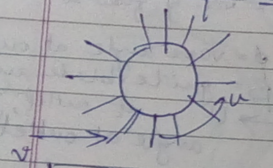
β is acute - $F_x = \rho a V_{r_1} [V_{w_1} + V_{w_2}]$
$\beta = \pi/2$ - $F_x = \rho a V_{r_1} [V_{w_1}]$
$\beta > \pi/2$ $F_x = \rho a V_{r_1} [V_{w_1} - V_{w_2}]$

work done $\boxed{W = \cancel{F_x}\ \rho a V_{r_1} [V_{w_1} \pm V_{w_2}] \times u}$

work done per sec per unit wt. of striking fluid = $\frac{[V_{w_1} \pm V_{w_2}] u}{g}$

work done / sec / unit mass of striking fluid = $(V_{w_1} \pm V_{w_2}) u$

Series of Vanes



$$\boxed{F_x = \rho a V[V-u]}$$

work done by jet on series of vanes

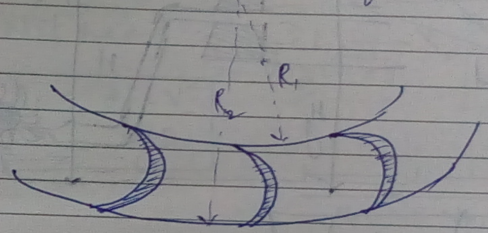
$$W \, ~~F_x~~ = \rho a V[V-u] \times u$$

$$\boxed{KE \text{ of jet} = \frac{1}{2}\rho a V^3}$$

$$\boxed{\eta = \frac{2u(V-u)}{V^2}} \qquad \boxed{\max \eta = 1/2} \rightarrow \boxed{u = V/2}$$

water enters and leaves without shock, $(V_{r_1} = V_{r_2})$

Force on series of Curved Vanes –



Torque exerted by water on the wheel

$$= \rho a V_1 [V_{w_1} R_1 + V_{w_2} R_2]$$

$$\text{Work done per second} = \rho a V_1 [V_{w_1} u_1 + V_{w_2} u_2] \quad \beta < \pi/2$$

$$= \rho a V_1 [V_{w_1} u_1 - V_{w_2} u_2] \quad (\beta > \pi/2)$$

$$\boxed{\eta = \frac{2(V_{w_1} u_1 \pm V_{w_2} u_2)}{V_1^2}}$$

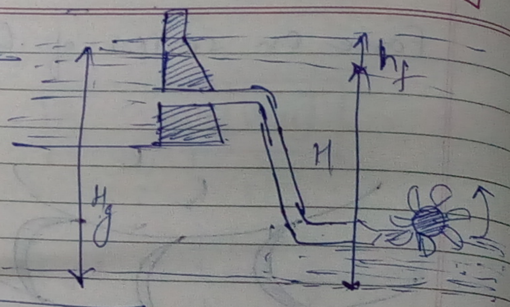
Work done (simple curved vane) $W = \rho a V_1 [V_{w_1} \pm V_{w_2}] u$

(series of vanes) $W = \rho a V_1 [V-u] \times u$

(series of curved vanes) $W = \rho a V_1 [V_{w_1} u_1 \pm V_{w_2} u_2]$

~~Pelton wheel~~

Gross Head



$\boxed{H \text{ (net head)} = H_g - h_f}$

$$\boxed{h_f = \frac{4fLV^2}{D\,\cancel{d} \times 2g}}$$

V = vel. of flow in penstock
L = length of penstock
D ~~d~~ = dia. of penstock
f = frictional coefficient.

sequence → Water Power – helps rotate runner – generates runner power – helps rotate shaft – generates shaft power

$\boxed{WP - RP - SP}$

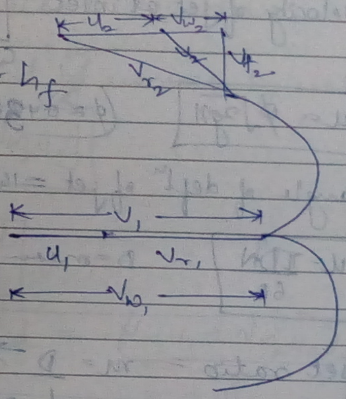
$$\boxed{\eta_h = \frac{RP}{WP}}$$

$$\boxed{WP = \frac{\rho g Q H}{1000}}$$

$$\boxed{\eta_m = \frac{SP}{RP}}$$

$$\boxed{\eta_o = \eta_h \times \eta_m}$$

Pelton wheel



Net head = $H_g - h_f$

$$\boxed{h_f = \frac{4fLV^2}{2gD}}$$

$$\boxed{F_x = \rho a V_1 [V_{w_1} + V_{w_2}]}$$

$\boxed{\text{work done by jet on runner} = \rho a V_1 [V_{w_1} + V_{w_2}]\, u}$

Power given to runner by jet = $\frac{\rho a V_1 [V_{w_1} + V_{w_2}] \times u}{1000}$

$$\boxed{\text{work done/second} = \frac{[V_{w_1} + V_{w_2}]\, u}{g}}$$

$$\boxed{\text{KE of jet per second} = \frac{(\rho a V_1) V_1^2}{2}}$$

$$\boxed{\eta_h = \frac{2[V_{w_1} + V_{w_2}] \times u}{V_1^2} = \frac{2(V_1 - u)(1 + \cos\phi)\, u}{V_1^2}}$$

$$\boxed{\eta_{h_{max}} \Rightarrow u = \frac{V_1}{2}} = \boxed{\frac{1 + \cos\phi}{2}}$$

i) velocity of jet at inlet = $\boxed{V_1 = C_v\sqrt{2gH}}$

$C_v = 0.98$ or 0.99

ii) $\boxed{u = \phi\sqrt{2gH}}$ ($\phi \approx 0.43$ to 0.48)

iii) angle of defl^n of jet = 165° by default.

iv) $\boxed{u = \frac{\pi D N}{60}}$ D = mean dia

v) Jet ratio = $m = \frac{D}{d}$ D → dia of pelton wheel

d → dia. of jet.

vi) No. of buckets $\boxed{Z = 15 + \frac{D}{2d}}$

vii) No. of jets = $\frac{\text{Total rate of flow}}{\text{rate of water through a single jet}}$

Design of Pelton wheel
width of buckets = 5d
depth of buckets = 1.2d

Radial Flow Reaction Turbine

Work done per second ~~of~~ on runner by water

$$\boxed{= \rho a V_1 \left[V_{w_1}u_1 \pm V_{w_2}u_2\right]}$$

$\boxed{u_1 = \frac{\pi D_1 N}{60}}$ $\boxed{u_2 = \frac{\pi D_2 N}{60}}$

$$\boxed{\text{work done per second} = \frac{(V_{w_1}u_1 \pm V_{w_2}u_2)}{g}}$$

if $\beta = 90°$ radial discharge $\boxed{\text{work} = \frac{V_{w_1}u_1}{g}}$

$\boxed{\eta_h = \frac{V_{w_1}u_1 \pm V_{w_2}u_2}{gH}}$ $\boxed{\text{for radial discharge } \eta_h = \frac{V_{w_1}u_1}{gH}}$

$\boxed{\text{speed ratio} = \frac{u_1}{\sqrt{2gH}}}$ $\boxed{\text{flow ratio} = \frac{V_{f_1}}{\sqrt{2gH}}}$

Discharge of turbine $\boxed{Q = \pi D_1 B V_f}$

D_1 → dia of runner at inlet

B → width of runner at inlet

V_f → vel. of flow at inlet.

$\boxed{H = \frac{p_1}{w} + \frac{V_1^2}{2g}}$

$$H - \frac{V_2^2}{2g} = \frac{(V_{w_1}u_1 \pm V_{w_2}u_2)}{g}$$

.Com

Francis Turbine

~~[illegible]~~ Inward radial flow reaction turbine.

Kaplan Turbine

Axial flow reaction turbine.

$$\boxed{Q = \frac{\pi}{4}(D_o^2 - D_b^2) \times V_{f_1}}$$

$$\boxed{u_1 = u_2 = \frac{\pi D_o N}{60}}$$

$$\boxed{V_{f_{inlet}} = V_{f_{outlet}}}$$

Area of flow at inlet

$$\frac{\pi}{4}(D_o^2 - D_b^2)$$

Specific Quantities

speed of a turbine identical to given turbine that produces unit power under unit head.

$$\boxed{N_S = \frac{N\sqrt{P}}{Q^{5/4}}}$$

Unit Speed

speed working under unit head,

$$N_u = \frac{N}{\sqrt{H}}$$

Unit Discharge $Q_u = \frac{Q}{\sqrt{H}}$

discharge under 1m.

Unit Power - $P_u = \frac{P}{H^{3/2}}$

Dynamics Of Fluid Flow

Bernoulli's Eqn

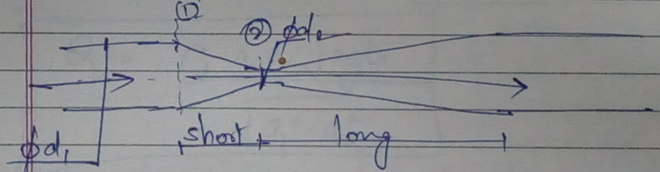
$$\frac{P}{\rho g} + \frac{V^2}{2g} + z \rightarrow \text{datum head} = \text{Constant}$$

pr. head
vel. head

for real fluid

$$\frac{P_1}{\rho_1 g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho_2 g} + \frac{V_2^2}{2g} + z_2 + h_L \rightarrow \text{losses}$$

Venturimeter



$$\boxed{V_2 = \frac{a_1\sqrt{2gh}}{\sqrt{a_1^2 - a_2^2}}}$$

$$\boxed{Q = C_d \frac{a_1 a_2 \sqrt{2gh}}{\sqrt{a_1^2 - a_2^2}}}$$

Values of "h" —

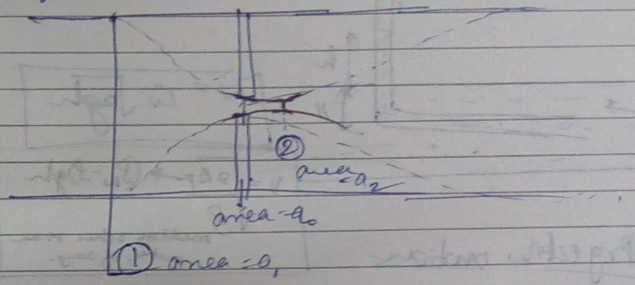
In case manometric liquid is heavier than that in venturimeter —

$$\boxed{h = \underset{\substack{\downarrow \\ \text{diff in levels}}}{x}\left[\frac{S_{mano}}{S_{fluid}} - 1\right]}$$

If otherwise, $\boxed{h = x\left[1 - \frac{S_{mano}}{S_{fluid}}\right]}$

for inclined manometer

orificemeter —

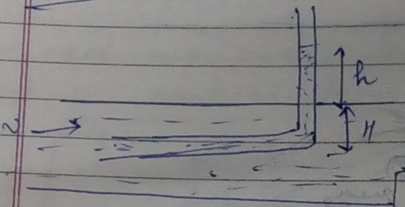


C_c = coeff. of contraction = $\frac{a_2}{a_0}$

$$\boxed{v_2 = \sqrt{2gh + \frac{a_0^2 C_c^2 v_2^2}{a_1^2}}} \quad \boxed{= \frac{\sqrt{2gh}}{\sqrt{1 - \left(\frac{a_0}{a_1}\right)^2 (C_c)^2}}}$$

$$\boxed{Q = \frac{C_d\, a_0 a_1 \sqrt{2gh}}{\sqrt{a_1^2 - a_0^2}}}$$

Pitot tube



$$\boxed{v = C_v\sqrt{2gh}}$$

$$\boxed{v = \sqrt{\frac{2\Delta p \rightarrow (\rho_w-\rho)gh}{\rho}}}$$

ρ medium other than water, if any.

Progectile motion

Time taken to reach highest point $\boxed{T' = \frac{u\sin\alpha}{g}}$

~~Time of flight~~ $\boxed{y_{max} = \frac{u^2\sin^2\alpha}{2g}}$

$$\boxed{T = \frac{2u\sin\alpha}{g}}$$

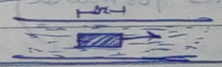
$$\boxed{\text{Range} = \frac{u^2\sin 2\alpha}{g}}$$

Viscous Flow

Cases

① Flow of viscous fluid through circular pipe
② between 2 parallel plates.
③ KE correction & momentum correction factors
④ Power absorbed in viscous flow

Reynolds No. $R_e = \dfrac{\rho \overset{\rightarrow \text{avg. velocity}}{V} \overset{\rightarrow \text{dia of pipe}}{D}}{\underset{\text{viscosity of fluid}}{\mu}}$



Shear force in dirⁿ of flow = $\tau = \left(\dfrac{-\partial p}{\partial x}\right)\left(\dfrac{r}{2}\right)$

Velocity Distribution

$$u = \frac{-1}{4\mu}\frac{\partial p}{\partial x}\left[R^2 - r^2\right]$$

$U_{max}\,(r=0)$

Average velocity = $\dfrac{\text{discharge of fluid across cross-section}}{\text{area of pipe } (\pi R^2)}$

$$\bar{u} = \frac{R^2}{8\mu}\left(\frac{-\partial p}{\partial x}\right)$$

$$\frac{u_{max}}{\bar{u}} = 2$$

100 YEAR CALENDER

YEARS							
2001	A	2026	D	2051	G	2076	J
2002	B	2027	E	2052	H	2077	E
2003	C	2028	M	2053	C	2078	F
2004	K	2029	A	2054	D	2079	G
2005	F	2030	B	2055	E	2080	H
2006	G	2031	C	2056	M	2081	C
2007	A	2032	K	2057	A	2082	D
2008	I	2033	F	2058	B	2083	E
2009	D	2034	G	2059	C	2084	M
2010	E	2035	A	2060	K	2085	A
2011	F	2036	I	2061	F	2086	B
2012	N	2037	D	2062	G	2087	C
2013	B	2038	E	2063	A	2088	K
2014	C	2039	F	2064	I	2089	F
2015	D	2040	N	2065	D	2090	G
2016	L	2041	B	2066	E	2091	A
2017	G	2042	C	2067	F	2092	I
2018	A	2043	D	2068	N	2093	D
2019	B	2044	L	2069	B	2094	E
2020	J	2045	G	2070	C	2095	F
2021	E	2046	A	2071	D	2096	N
2022	F	2047	B	2072	L	2097	B
2023	G	2048	J	2073	G	2098	C
2024	H	2049	E	2074	A	2099	D
2025	C	2050	F	2075	B	2100	E

MONTHS												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
A	1	4	4	7	2	5	7	3	6	1	4	6
B	2	5	5	1	3	6	1	4	7	2	5	7
C	3	6	6	2	4	7	2	5	1	3	6	1
D	4	7	7	3	5	1	3	6	2	4	7	2
E	5	1	1	4	6	2	4	7	3	5	1	3
F	6	2	2	5	7	3	5	1	4	6	2	4
G	7	3	3	6	1	4	6	2	5	7	3	5
H	1	4	5	1	3	6	1	4	7	2	5	7
I	2	5	6	2	4	7	2	5	1	3	6	1
J	3	6	7	3	5	1	3	6	2	4	7	2
K	4	7	1	4	6	2	4	7	3	5	1	3
L	5	1	2	5	7	3	5	1	4	6	2	4
M	6	2	3	6	1	4	6	2	5	7	3	5
N	7	3	4	7	2	5	7	3	6	1	4	6

CALENDARS							
	1	2	3	4	5	6	7
Monday	1						
Tuesday	2	1					
Wednesday	3	2	1				
Thursday	4	3	2	1			
Friday	5	4	3	2	1		
Saturday	6	5	4	3	2	1	
Sunday	7	6	5	4	3	2	1
Monday	8	7	6	5	4	3	2
Tuesday	9	8	7	6	5	4	3
Wednesday	10	9	8	7	6	5	4
Thursday	11	10	9	8	7	6	5
Friday	12	11	10	9	8	7	6
Saturday	13	12	11	10	9	8	7
Sunday	14	13	12	11	10	9	8
Monday	15	14	13	12	11	10	9
Tuesday	16	15	14	13	12	11	10
Wednesday	17	16	15	14	13	12	11
Thursday	18	17	16	15	14	13	12
Friday	19	18	17	16	15	14	13
Saturday	20	19	18	17	16	15	14
Sunday	21	20	19	18	17	16	15
Monday	22	21	20	19	18	17	16
Tuesday	23	22	21	20	19	18	17
Wednesday	24	23	22	21	20	19	18
Thursday	25	24	23	22	21	20	19
Friday	26	25	24	23	22	21	20
Saturday	27	26	25	24	23	22	21
Sunday	28	27	26	25	24	23	22
Monday	29	28	27	26	25	24	23
Tuesday	30	29	28	27	26	25	24
Wednesday	31	30	29	28	27	26	25
Thursday		31	30	29	28	27	26
Friday			31	30	29	28	27
Saturday				31	30	29	28
Sunday					31	30	29
Monday						31	30
Tuesday							31

These Charts Enable You Find the day of the week in any year from 2001 to 2100

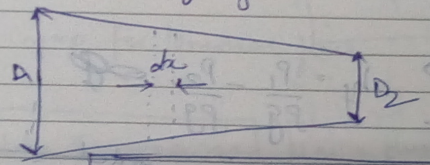
INSTRUCTIONS

STEP 1
Find the year that you are interested and note the alphabet that follow it.

STEP 2
Find that letter above and note which number falls under the month you are looking for.

STEP3
Use the calender that bears the number you found in step 2.

Pipe of Varying Diameter



$$\boxed{\Delta p = \frac{128\mu Q l}{3\pi(D_1 - D_2)}\left[\frac{1}{D_1^3} - \frac{1}{D_2^3}\right]}$$

KE correction factor

$$\alpha = \frac{\text{KE/s based on actual velocity}}{\text{KE/s based on average velocity}}$$

Momentum correction factor

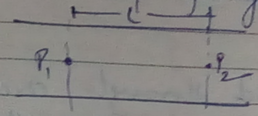
$$\beta = \frac{\text{Momentum per second based on actual velocity}}{\text{Momentum per second based on avg. velocity}}$$

For laminar flow through circular pipe

$\alpha = 2$ $\beta = 4/3$

$$\boxed{\bar{u} = \frac{Q}{\text{area of cross-section}}}$$

Pressure Drop for given length of pipe



$$\boxed{P_1 - P_2 = \Delta p = \frac{32\mu\bar{u}L}{D^2}}$$

$$\boxed{\text{Loss of pressure head} = \frac{P_1 - P_2}{\rho g} = h_f = \frac{32\mu\bar{u}L}{\rho g D^2}}$$

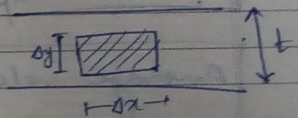
(Hagen-Poiseuille formula)

Flow of Viscous Fluid Between 2 parallel plates

$$\boxed{\frac{\partial p}{\partial x} = \frac{\partial \tau}{\partial y}}$$

$$\boxed{u = \frac{1}{2\mu}\frac{\partial p}{\partial x}y^2 + y\left(-\frac{1}{2\mu}\frac{\partial p}{\partial x}\right)t}$$

$$\boxed{u = \frac{\partial p}{\partial x}\frac{1}{2\mu}(y^2 - ty)}$$



$$\boxed{\bar{u} = \frac{-t^2}{12\mu}\frac{\partial p}{\partial x}}$$

$$\boxed{\frac{u_{max}}{\bar{u}} = \frac{3}{2}}$$

$$\boxed{\text{Pressure Drop } \Delta p = \frac{12\mu\bar{u}L}{t^2}}$$

Shear stress $\boxed{\tau = -\frac{1}{2}\frac{\partial p}{\partial x}(t - 2y)}$

Total Shear Stress $\boxed{\tau = \tau_v + \tau_t = \mu \frac{du}{dy} + \eta \frac{d\bar{u}}{dy}}$

$\eta = 0$ for laminar flow.

Reynolds Expression
$\tau = \rho \overline{u'v'}$

u', v' = fluctuating component of velocity in x & y dirⁿ.

Prandtl Mixing length Theory
Primary criteria $(u' = v')$

$$\boxed{\bar{\tau} = \rho l^2 \left(\frac{du}{dy}\right)^2}$$

$$\therefore \boxed{\bar{\tau} = \mu \frac{du}{dy} + \rho l^2 \left(\frac{du}{dy}\right)^2}$$

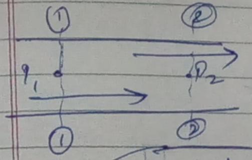
Velocity Distribution In Turbulent Flow In Pipes

($\mu \frac{du}{dy}$ has significant values only near the boundaries)

$$\therefore \tau = \rho l^2 \left(\frac{du}{dy}\right)^2$$

let $l = Ky$, $\boxed{\left(\frac{du}{dy}\right)^2 = \frac{\tau}{\rho K^2 y^2}} \Rightarrow \boxed{\frac{du}{dy} = \frac{1}{Ky}\sqrt{\frac{\tau}{\rho}}}$

Turbulent Flow



$$h_f = \frac{p_1}{\rho g} - \frac{p_2}{\rho g}$$

$$= \frac{f'}{\rho g} \times \frac{P}{A} \times L \times V^2$$

$f' \rightarrow$ frictional resistance per unit wetted area per unit velocity

$V \rightarrow$ vel. at section ①①.

$$\boxed{h_f = \frac{4fLV^2}{2gD}}$$

$$\boxed{f = \frac{2\tau_0}{\rho V^2}}$$

Shear Stress In Turbulent Flow

Shear stress due to viscosity $\tau_v = \mu \frac{du}{dy}$

Turbulent shear stress $\tau_t = \eta \frac{d\bar{u}}{dy}$

$\bar{u} \rightarrow$ avg. vel. at distance y from boundary

$\eta \rightarrow$ eddy viscosity

Kinematic eddy viscosity $\varepsilon = \frac{\eta}{\rho}$

$\eta \rightarrow$ eddy viscosity

$\rho \rightarrow$ mass density

H

For small values of y (close to boundary),
$\tau \approx \tau_0$ (constant)

$$\therefore \frac{du}{dy} = \frac{1}{\kappa y}\sqrt{\frac{\tau_0}{\rho}}$$

let $\sqrt{\frac{\tau_0}{\rho}} = u_*$ $\Rightarrow$ $\frac{du}{dy} = \frac{u_*}{\kappa y}$

$$\Rightarrow \boxed{u = \frac{u_*}{\kappa}\log_e y + C}$$

$$\left(C = u_{max} - \frac{u_*}{\kappa}\log_e R\right)$$

$$\Rightarrow \boxed{u = u_{max} + \frac{u_*}{0.4}\log_e\left(\frac{y}{R}\right)}$$

$$\boxed{\frac{u_{max} - u}{u_*} = 5.75\log_{10}\left(\frac{R}{y}\right)}$$

($u_{max} - u$ = velocity defect)

Hydrodynamically smooth & rough boundaries
K avg ht of irregularities δ' = thickness of laminar sub layer

Smooth	$K/\delta' < 0.25$	$\frac{u_* K}{\nu} < 4$
In transition	$0.25 < K/\delta' < 6$	$4 < \frac{u_* K}{\nu} < 100$
Rough	$K/\delta' > 6$	> 100

Flow Through Pipes

Laws Of Friction

① Streamline

→ $\propto$ velocity → $\propto$ surface area of contact

→ $\not\propto$ pressure → $\propto$ temp

→ independent of nature of surface of contact.

② Turbulent

→ $\propto v^2$ → $\propto \rho$ → $\propto$ surface area of contact.

→ $\not\propto$ pressure → $\propto$ temp

→ depends on nature of surface of contact.

Major Losses

① Darcy-Weisbach Eqn

$$\boxed{h_f = \frac{4fLV^2}{2gd}}$$

L = length of flow
V = mean vel. of pipe
d = dia. of pipe

$$\boxed{f = \frac{16}{R_e} \quad R_e < 2000} \quad \boxed{f = \frac{0.079}{R_e^{1/4}} \quad 4000 < R_e < 10^6} \quad f:$$

if pipe isn't circular, $h_f = \frac{fLV^2}{2gm}$

$$\boxed{m = \frac{\text{area of pipe}}{\text{perimeter of pipe}}}$$

$$\boxed{h_f = \frac{fLQ^2}{3.025\, d^5}}$$

Losses in Kinetic Heads

Sudden expansion of pipe

$$\boxed{h_e = \frac{(V_1 - V_2)^2}{2g}}$$

Sudden contraction of pipe

$$h_c = \frac{V_2^2}{2g}\left[\frac{1}{C_c} - 1\right]^2$$

C_c is usually 0.62

if C_c not given, $h_c = \frac{0.5 V_2^2}{2g}$

loss of ~~entrance~~ head at entrance $h_i = \frac{0.5 V^2}{2g}$.

loss of head at exit $h_o = \frac{V^2}{2g}$

loss due to obstruction $= \frac{V^2}{2g}\left(\frac{A}{C_c(A-a)} - 1\right)^2$

loss of head in bend $h_b = \frac{KV^2}{2g}$

loss of head in various fittings $\frac{KV^2}{2g}$

$\sqrt{h}\frac{g^2}{2g}x$ d/a

Chezy's Equn

$$h_f = \frac{f'}{\rho g} \times \left(\frac{P}{A}\right) \times L \times V^2$$

$m = \frac{A}{P} = \frac{\text{area}}{\text{perimeter}} = (\text{hydraulic mean depth})$

$m = \frac{A}{P} = d/4$

$\boxed{\therefore V = c\sqrt{mi}}$

$\boxed{c = \sqrt{\frac{\rho g}{f'}}}$ $\boxed{i = \frac{h_f}{L}}$

$$\Rightarrow H = \left[\frac{0.5V_1^2}{2g} + \frac{4fLV_1^2}{2g}\right] + \left[\frac{0.5V_2^2}{2g} + \frac{4fLV_2^2}{2g}\right] + \left[\frac{(V_2-V_3)^2}{2g} + \frac{4fLV_3^2}{2g}\right] + \left[\frac{V_2^2}{2g}\right]$$

if minor losses are neglected,

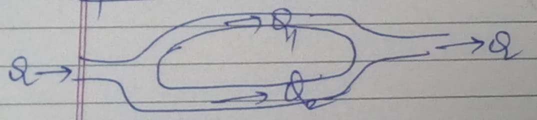
$$H = \frac{4fLV_1^2}{2g} + \frac{4fLV_2^2}{2g} + \frac{4fLV_3^2}{2g}$$

Equivalent pipe

$$\frac{4fLV^2}{2g} = \sum \frac{4f_iL_iV_i^2}{2g}$$

$$\frac{L_1}{d_1^5} + \frac{L_2}{d_2^5} + \frac{L_3}{d_3^5} = \frac{L}{d^5} \quad \text{or} \quad \frac{L}{d^5} = \sum \frac{L_i}{d_i^5}$$

Pipes In Parallel



$$Q = Q_1 + Q_2$$

loss of head in ① = loss of head in ②

Hydraulic Gradient Line

= sum of $\frac{P}{w} + Z$

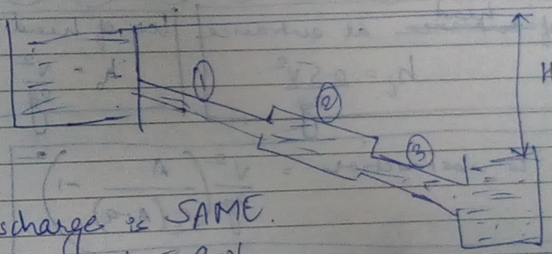
pr. head ; datum head

Total Energy line

pr head + datum head + kinetic head

$\frac{P}{w} + z + [\ ]$ → as shown in previous articles

Pipes In Series



Discharge is SAME.

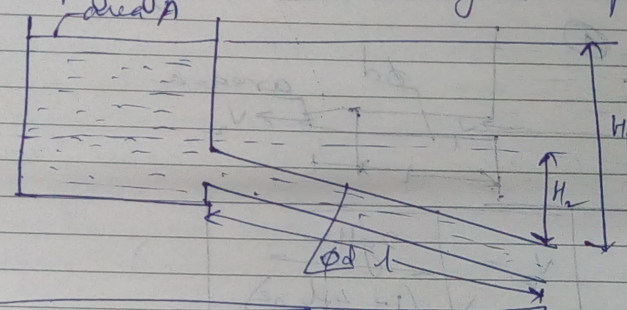
$a_1V_1 = a_2V_2 = a_3V_3$

Total head losses =

~~loss of entry in ① + loss of entry in ② + loss of entry in ③.~~

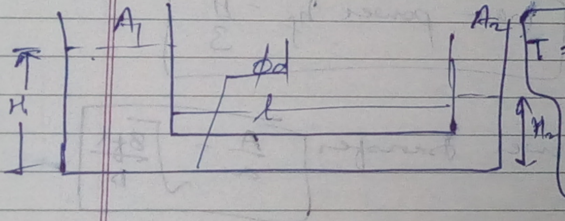
loss of entry in ① + friction in ① +
sudden expansion from ① to ② + friction in ② +
sudden contraction from ② to ③ + friction in ③ +
loss at exit from ③ to reservoir.

Emptying A Tank through A Pipe



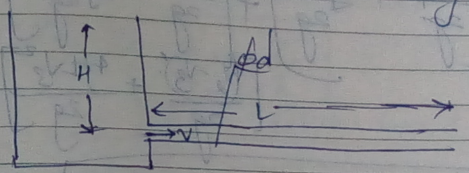
$$T = \frac{2A}{\left(\frac{\pi d^2}{4}\right)} \sqrt{\frac{1.5 + \frac{4fl}{d}}{2g}} \left[\sqrt{H_1} - \sqrt{H_2}\right]$$

Flow from One tank to other



$$T = \frac{2A \sqrt{1.5 + \frac{4fl}{d}} \left[\sqrt{H_1} - \sqrt{H_2}\right]}{\left[1 + \frac{A_1}{A_2}\right] a\sqrt{2g}}$$

Power Transmission Through Pipes



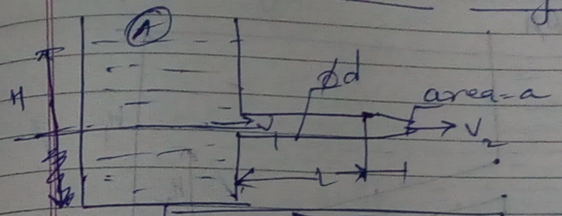
$$P = \frac{\rho g}{1000} \times \left(\frac{\pi d^2}{4}\right) \times v \left(H - \frac{4flv^2}{2gd}\right)$$ kw

$$\eta = \frac{H - h_f}{H}$$

max power $h_f = \frac{H}{3}$

$$\max \eta = \frac{2}{3}$$

Power Transmission Through Nozzles



$$V_2 = \sqrt{\frac{2gH}{\left(1 + \frac{4fL}{D}\frac{a^2}{A^2}\right)}}$$

power transmitted $= \frac{\rho a V_2^3}{2 \times 1000}$ kW

$\eta = \frac{V_2^2}{2gH}$

max. power $h_f = \frac{H}{3}$

Dia for max. power transfer $\frac{A}{a} = \sqrt{\frac{8fL}{D}}$

15→6

Von Karman Integral

$$\frac{\tau_0}{\rho U^2} = \frac{\partial \theta}{\partial x}$$

$$\rightarrow \theta = \int_0^\delta \frac{u}{U}\left(1 - \frac{u}{U}\right) dy$$

Boundary layer Flow

When fluid moves past an object or object moves through a fluid, the fluid close to the boundary has no velocity (ideally). But as we move further apart, the variation of velocity from zero to free stream velocity in dir^n normal to free stream velocity, in a narrow region called boundary layer.

Types –

Laminar boundary layer –
Laminar Sub layer (turbulent)

$$\boxed{\delta^* = \text{displacement thickness} = \int_0^\delta \left(1 - \frac{u}{U}\right) dy}$$

δ = boundary layer thickness
= distance from boundary layer to point with speed of 0.99x free stream velocity.

$$\boxed{\text{Momentum thickness } \theta = \int_0^\delta \frac{u}{U}\left(1 - \frac{u}{U}\right) dy}$$

$$\boxed{\text{Energy thickness } \delta^{**} = \int_0^\delta \frac{u}{U}\left(1 - \frac{u^2}{U^2}\right) dy}$$